

CONAXIS – EXAMPLE 3

Modelling unit cell with stress-dependent parameters

1. Problem description

In this example, we deal with a typical soft soil treatment problem using prefabricated vertical drains (PVDs) and vacuum pumping (Table 1).

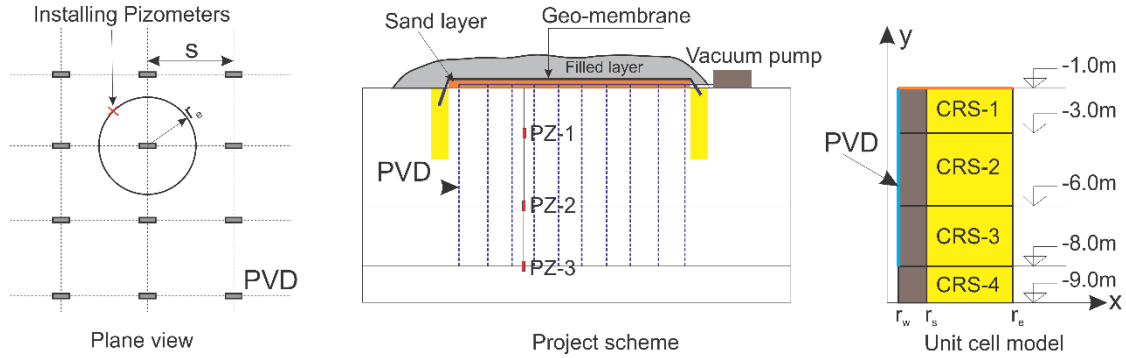


Figure 1: Model scheme

A project has a 9.0m layer of the soft soil that is divided into 4 layers. The constant rate of strain tests are conducted for each layer, namely CRS-1, CRS-2, CRS-3, CRS-4. To improve the shear strength of soil, the treatment method is to combine the vacuum pumping, the surcharge loading, and PVDs.

The construction process is given in Table 1, and the soil properties is given in Table 2.

Table 1: Construction process

Tasks	From (day)	To (day)	Duration (day)
Installing PVDs	0	10	10
Filling 0.5m sand layer	10	15	5
Pumping vacuum (80kPa)	15	115	100
Filling 2.0m compensation layer	50	100	50

Table 2: Soil properties

Layer	Thickness (m)	Unit weight (kN/m ³)	Void ratio	Ratio k_h / k_v	Ratio k_s / k_h
Layer-1	2.0	16.4	1.6	3.0	0.33
Layer-2	3.0	15.2	1.841	3.0	0.33
Layer-3	2.0	15.7	1.810	3.0	0.33
Layer-4	1.0	15.9	1.823	3.0	0.33
Sand layer on the top	0.5	20	-	-	-
Filled layer	2.0	20	-	-	-

The length of PVD is 7.0m. Assuming that it takes 8 days to reach -80 kPa vacuum, and then the vacuum is kept for the whole process. By using excel, we calculate values of surcharge loading and vacuum pressure that depend on the construction time and save them as *surcharge.dat* and *vacuum.dat* file.

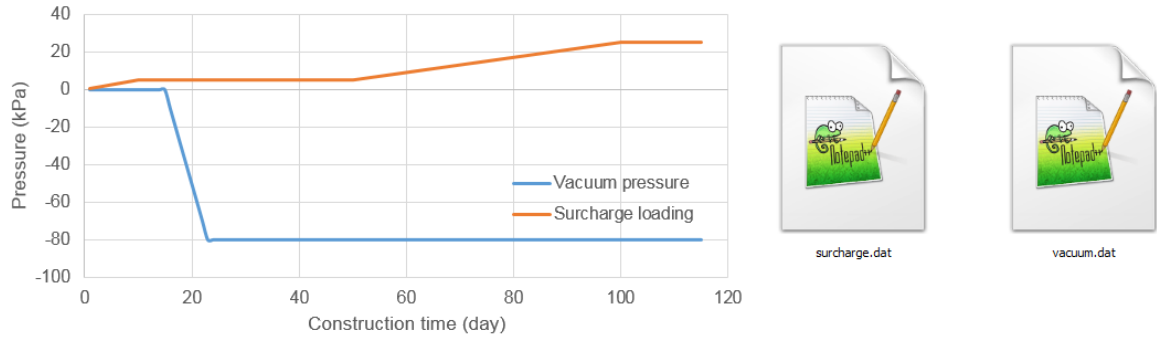


Figure 2: Surcharge loading and vacuum pressure over time

Three piezometers are installed at the elevation of -3.0m, -6.0m, and -8.0m (Figure 1).

The size of PVD is $100 \times 4 \text{ mm}$ and the size of the mandrel is $120 \times 60 \text{ mm}$. Hence, the equivalent radius of the PVD is:

$$r_w = \frac{0.5b + 0.7t}{2} = \frac{0.5 \times 0.1 + 0.7 \times 0.004}{2} = 0.0264 \text{ m}$$

The smear zone is twice as the mandrel size, the equivalent radius of the smear zone is:

$$r_s = 2 \times \frac{0.5 \times 0.12 + 0.7 \times 0.06}{2} = 0.102 \text{ m}$$

PVDs are installed with a rectangular pattern. The distance between each PVDs is $s = 1.0 \text{ m}$. Hence, the radius of the unit cell is: $r_e = 0.565 \times s = 0.565 \text{ m}$.

For this analysis, we need to find:

- The settlement of the surface over time.
- The development of excess pore pressure of the Piezometers.

2. Step 1: Back-analysis

Data of CRS tests are saved as *CRS-1.dat*, *CRS-2.dat*, *CRS-3.dat*, *CRS-4.dat*. Following the example-2, we do the back analysis with the following input parameters:

- The initial height of sample: $H_0 = 0.0254 \text{ m}$
- The radius of the sample: $R = 0.03175 \text{ cm}$
- Poisson's ratio: $\nu = 0.35$

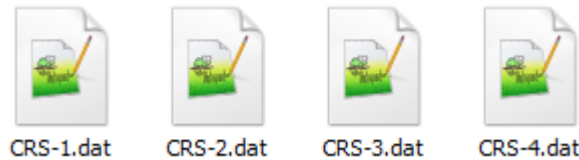


Figure 3: Data of CRS tests

After the back analysis process, we obtain results as *CRS-1-BA.dat*, *CRS-2-BA.dat*, *CRS-3-BA.dat*, *CRS-4-BA.dat*.

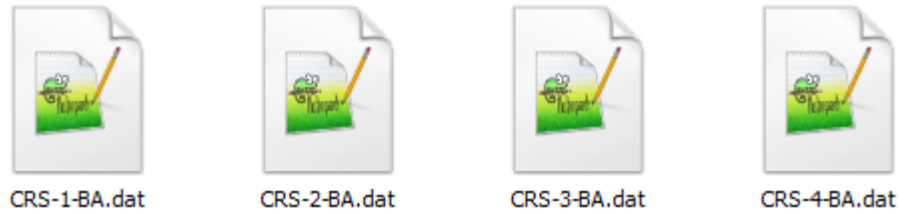


Figure 4: Results after back analysis

3. Step 1: Create a mesh

Click *Geometry/Create mesh*. We input information as Figure 5.

Create Mesh

Unit cell Radius (m) Number of Layer

Smear-zone Radius (m) Smear-zone elements

PVD Radius (m) Undisturbed-zone elements

PVD Length (m) Discharge capacity (m3/s)

Surface elevation (m) Default Sub-Layer

Layer #	Thickness (m)	Material #	Sub-layer
1 1	2	1	5
2 2	3	2	5
3 3	2	3	5
4 4	1	4	5

3- Smear - No Well Resistance

Diagram Labels: 2 smear elements, 4 soil elements, Surface Elev.(m), Layer-1, Layer-2, 3 Sub-layers, Layer-3, Layer-4, PVD, r_w , r_s , r_e , X, y, Layer thickness.

Figure 5: Parameters to create the mesh.

Click *Update* and *Create Mesh*. The mesh will be displayed on the main window. To have a better view, click *Plot Control / Pick Result and Scale Setting*, and put 5.0 to *X-coordinate scale*. The final mesh looks like Figure 6. Different colours represent different layer.

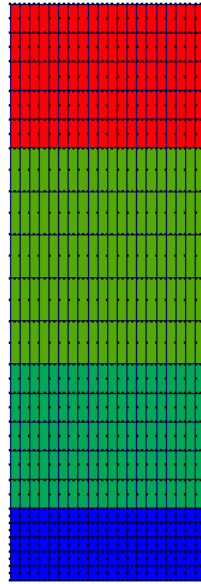


Figure 6: The mesh after scaling the x-direction five times

4. Step 2: Defining material

Click *Material / Create Material*. For the Material #1, choose the bulk modulus type as Figure 7. Then a dialog pops out and we browse to the file *CRS-1-BA.dat*. Repeating with the hydraulic conductivity.

Figure 7: Choosing bulk modulus type and vertical hydraulic conductivity type

The other information is taken from Table 2. It is noted that the unit weight is the buoyant unit weight.

Create/Modify Material

Material #

Bulk Modulus

From File:

Poisson's Ratio

Vertical hydraulic conductivity kv

From File:

Ratio kh/kv

Unit weight

Initial Void Ratio

ks/kh factor

Figure 8: Material #1

Repeating with Material #2 (Figure 9), Material #3 (Figure 10), and Material #4 (Figure 11).

Create/Modify Material

Material #

Bulk Modulus

Input From File

Poisson's Ratio

Vertical hydraulic conductivity kv

Input From File

Ratio kh/kv

Unit weight

Initial Void Ratio

ks/kh factor

Figure 9: Material #2

Create/Modify Material [?] [X]

Material #

Bulk Modulus

Input From File

Poisson's Ratio

Vertical hydraulic conductivity kv

Input From File

Ratio kh/kv

Unit weight

Initial Void Ratio

ks/kh factor

Figure 10: Material #3

Create/Modify Material [?] [X]

Material #

Bulk Modulus

Input From File

Poisson's Ratio

Vertical hydraulic conductivity kv

Input From File

Ratio kh/kv

Unit weight

Initial Void Ratio

ks/kh factor

Figure 11: Material #4

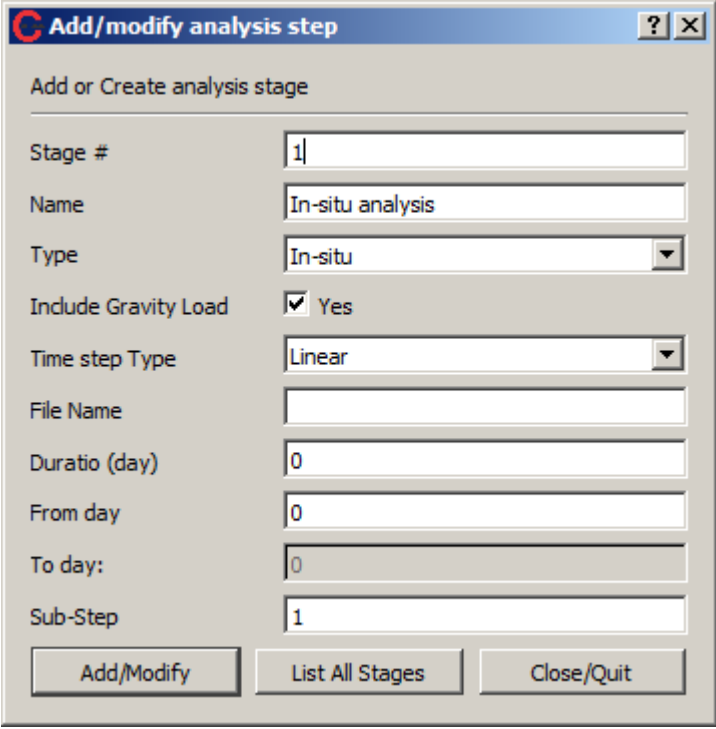
5. Step 3: Defining analysis stages

For this analysis, we have three stages (Table 3):

- **In-situ:** To generate the field stress. For this stage, the gravity load is included.
- **Before installing PVDs:** There is only vertical flow. However, there is no surcharge loading yet, hence we expect that nothing happens in this stage.
- **Filling sand layer:** The PVD boundary is set to drained, excess pore pressure is zero.
- **Vacuum pumping:** The PVD boundary and top boundary are assigned vacuum pressure (excess pore pressure is negative).

Table 3: Analysis stages

Stage	Start (day)	Duration (day)	Sub-step
In-situ	0	0	1
Before installing PVDs	0	10	20
Filling sand layer	10	5	10
Vacuum pumping	15	100	200



Add/modify analysis step

Add or Create analysis stage

Stage # 1

Name In-situ analysis

Type In-situ

Include Gravity Load ☒ Yes

Time step Type Linear

File Name

Duration (day) 0

From day 0

To day: 0

Sub-Step 1

Add/Modify List All Stages Close/Quit

Figure 12: In-situ

Add/modify analysis step [?] [X]

Add or Create analysis stage

Stage #	2
Name	Installing PVDs
Type	Consolidation
Include Gravity Load	<input type="checkbox"/> Yes
Time step Type	Linear
File Name	
Duration (day)	10
From day	0
To day:	10
Sub-Step	10

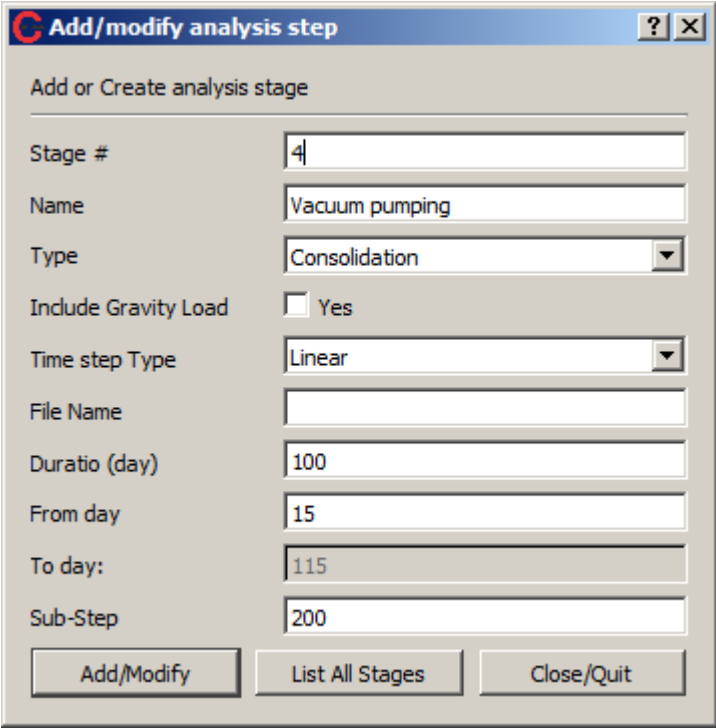
Figure 13: Installing PVDs stage

Add/modify analysis step [?] [X]

Add or Create analysis stage

Stage #	3
Name	Filling sand layers
Type	Consolidation
Include Gravity Load	<input type="checkbox"/> Yes
Time step Type	Linear
File Name	
Duration (day)	5
From day	10
To day:	15
Sub-Step	10

Figure 14: Filling sand layer



Add/modify analysis step

Add or Create analysis stage

Stage #

Name

Type

Include Gravity Load ☐ Yes

Time step Type

File Name

Duration (day)

From day

To day:

Sub-Step

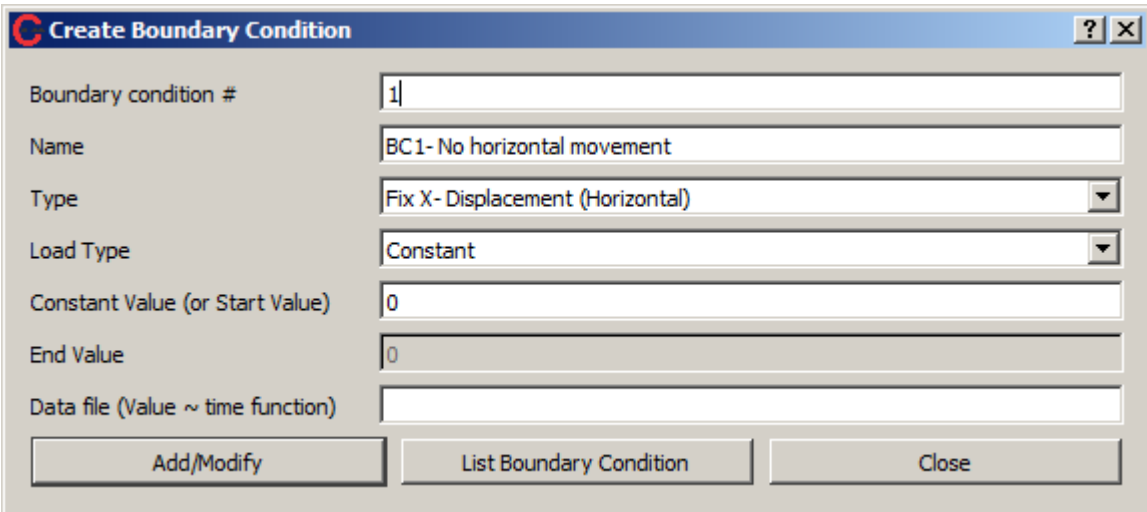
Figure 15: Vacuum pumping

6. Step 4: Defining boundary conditions

There are five type of boundary conditions for this analysis:

- BC1: No horizontal movement, for the left and the right side of the model.
- BC2: No vertical movement, for the bottom boundary
- BC3: Surcharge loading, for the top boundary
- BC4: Excess pore pressure is zero, for the top boundary and the PVD boundary
- BC5: Excess pore pressure is negative (vacuum)

To create boundary conditions, click *Boundary Condition / Add Boundary Condition*.



Create Boundary Condition

Boundary condition #

Name

Type

Load Type

Constant Value (or Start Value)

End Value

Data file (Value ~ time function)

Figure 16: Boundary condition #1

Create Boundary Condition

Boundary condition # 2

Name BC2-No vertical movement

Type Fix Y- Displacement (Vertical)

Load Type Constant

Constant Value (or Start Value) 0

End Value 0

Data file (Value ~ time function)

Add/Modify List Boundary Condition Close

Figure 17: Boundary condition #2

Create Boundary Condition

Boundary condition # 3

Name BC3 - Surcharge loading

Type Line Pressure: Y- Direction

Load Type Time dependence (from data file)

Constant Value (or Start Value) 0

End Value 0

Data file (Value ~ time function) ive/phD/8.Ca mau 1st paper -new/Examples/Example 3/Load/surcharge.dat

Add/Modify List Boundary Condition Close

Figure 18: Boundary condition #3

For the BC3, values in the file *surcharge.dat* is positive. However, because the direction of the load and the Y-axis is opposite. Hence, values must be scaled with the factor -1.0.

Create Boundary Condition

Boundary condition # 4

Name BC4- Zero EPWP

Type Fix Pore Pressure

Load Type Constant

Constant Value (or Start Value) 0

End Value 0

Data file (Value ~ time function)

Add/Modify List Boundary Condition Close

Figure 19: Boundary condition #4

Create Boundary Condition

Boundary condition #

Name

Type

Load Type

Constant Value (or Start Value)

End Value

Data file (Value ~ time function)

Figure 20: Boundary condition #5

7. Step 5: Assign boundary conditions to analysis stages

Click *Boundary Condition / Assign Boundary condition*. The boundary conditions are assigned to each stage as Figure 21.

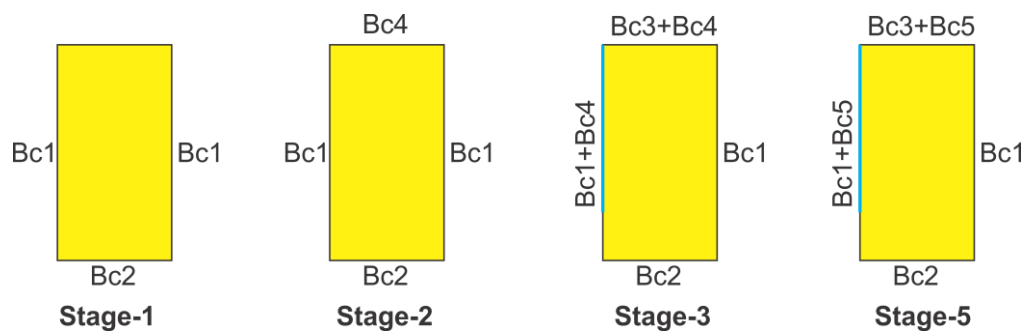


Figure 21: Boundary conditions for each stage

Analysis Stage	1		
Name of stage	In-situ analysis		
Boundary Condition (BC) #	1	Number	1
Name of boundary	BC1- No horizontal movement		
Assign To	Nodes with coordinate X,Y		
Varied with coordinates	<input type="checkbox"/> Yes (Value= $Ax+By+C$)		
Gradient factors (A,B,C)	A 0	B 0	C 0
X-Coordinate Range From:	0	To:	0
Y-Coordinate Range From:	-9	To:	-1
File name of list node			
<input type="button" value="Add boundary to stage"/> <input type="button" value="Reset"/> <input type="button" value="List All Information"/> <input type="button" value="Close/Quit"/>			

Figure 22: For instance, assign BC1 to nodes that have $x=0$, $y=-9.0$ to $y=-1.0$ (the left side)

8. Step 6: Defining watch lists

We need to have the settlement over time, and values of the excess pore pressure at piezometer positions. Hence, we create four watch lists (*Solve/ Monitoring points*)

9. Stage 7: Run analysis

Click *Run*. The final results are presented in Figure 23.

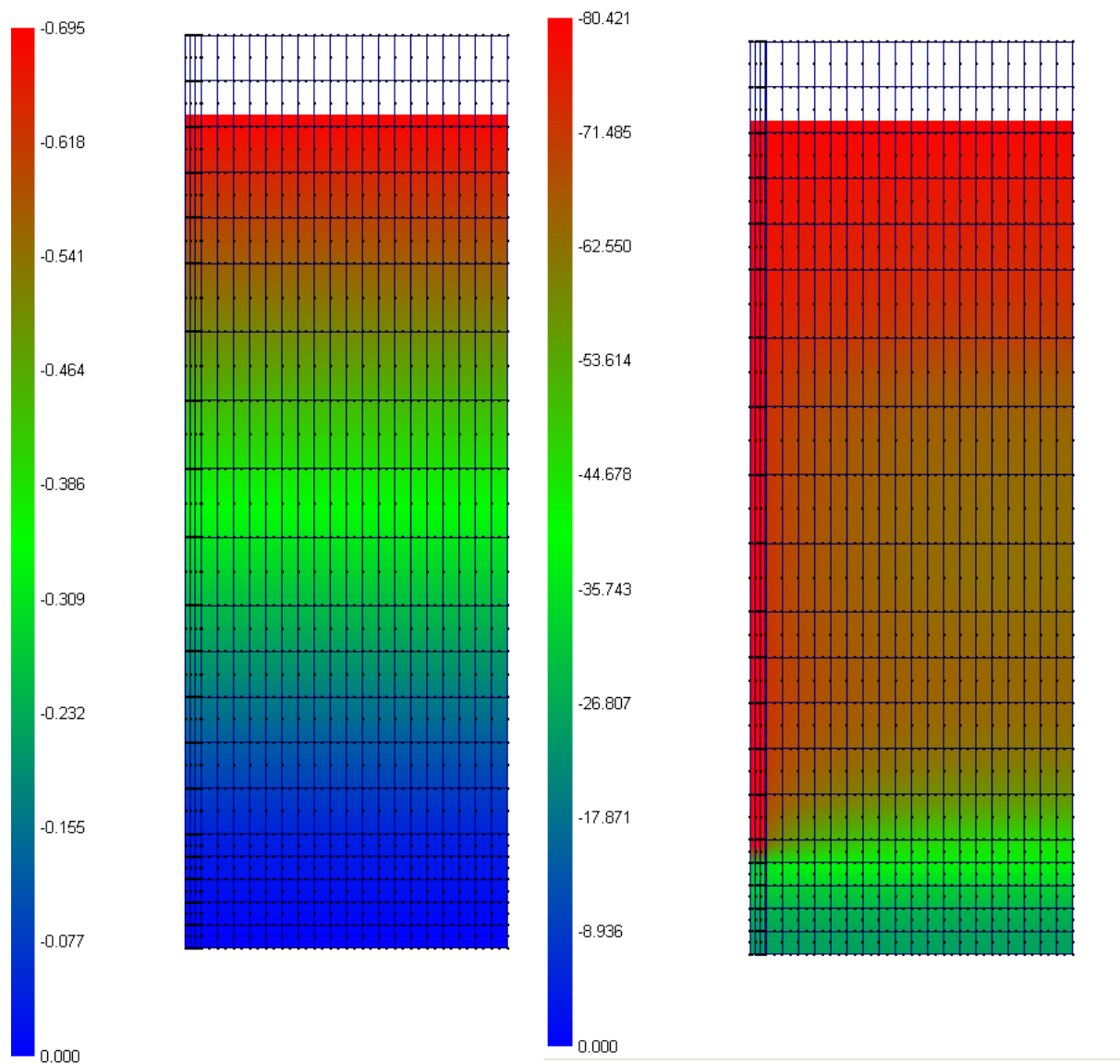


Figure 23: Final settlement and excess pore pressure